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Design of a test bench for traction drive systems in mobile machines

Different driveline architectures can be characterized by their specific features. The validation and evaluation of them depends on the conditions of their usage. To carry out an objective research a testing environment is required allowing examinations of alternative drivelines under the same conditions. This publication presents the development of a novel and to the experimental requirements adapted test bench, which allows testings of the different driveline architectures, especially in a self-propelled forage harvester. Furthermore, the single working steps are described – from the conception phase through conduction of experiments on the test bench including the final evaluation.

Keywords
Test bench, forage harvester, traction drive

Abstract
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8 references

The implementation of hybrid and especially electrical traction drive concepts in agricultural machines is in focus of current research and development [1–4]. An important approach is to identify possible potentials of electric and hydraulic drives and to compare advantages and disadvantages in case of a specific application. Therefore components and methods are needed to examine and evaluate possible system changes. A subtarget of this research project is the development of a test bench to examine and evaluate different traction drives in self-propelled forage harvesters. The project is funded by the Deutsche Bundesstiftung Umwelt and is carried out by Maschinenfabrik Bernard KRONE GmbH and the chair of Agricultural Systems Engineerung at Technische Universität München.

Material and methods

The decision towards a new development was made based on the following points:

- The project partners tried to find a solution excluding any influence of the tires, so a roller dynamometer was not used
- The components should remain within the machine during the tests. So any impact due to a varied piping and tubing can be excluded, which may occur, if the components are disassembled to be tested on an existing test bench.

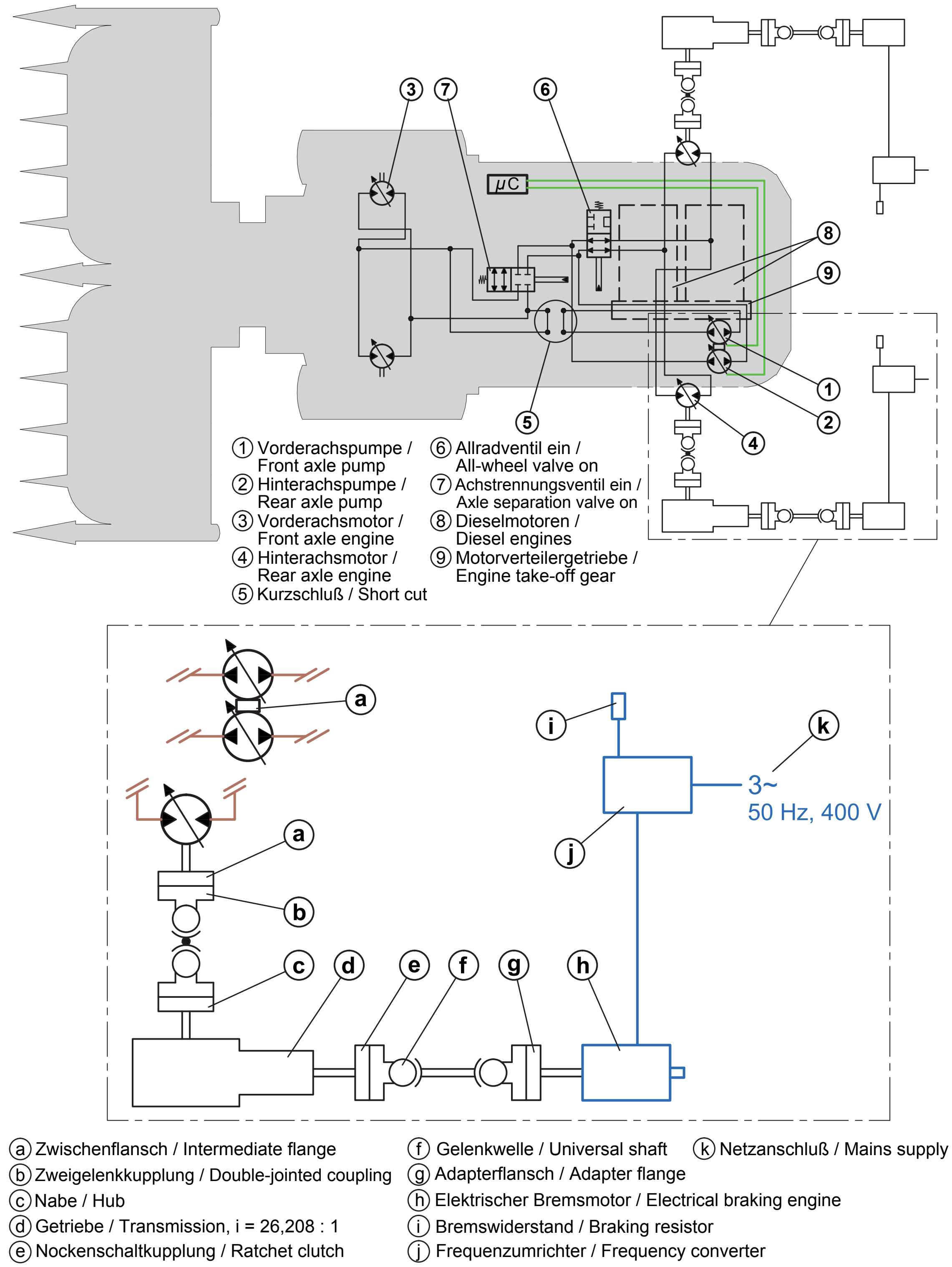
Therefore the main requirement for the test bench can be derived as a direct consequence: The test bench has to be adaptable to the machine conditions, which is also represented in the concept for the hydrostatic traction drive of the test carrier shown in **Figure 1**.

Therefore the front axle power unit tubes had been short-circuited, so that the hydraulic engines are not powered anymore. Due to this modification only the smaller one of the two traction drive pumps powers the rear axle engines [5]. Furthermore the mechanical power can be measured between the two pumps. In addition the wheel torques are measured directly at the wheel hub engine flanges. Different cupplings, gears and joints link the drive and the braking machines. A uniform loading of the wheel hub engines is possible by this test bench. The last problem, the differential effect of the hydrostatic serial axle drive, is solved by the electrical control of the braking machines. Both are running at the same speed. Otherwise small differences in the efficiency of the transmissions can lead to a relative high speed difference at the two braking machines.

Digital prototype

The digital prototype as well as the physical prototype of the test bench were designed and developed at the Institute for Agricultural Engineering and Animal Husbandry of the Bavarian State Research Center for Agriculture. The development and implementation were carried out with Pro/Engineer WF4, a fully parametric 3D CAD software package, which enabled the handling of the data through the entire process chain, from the sketch to the assembling of the real prototype. Building of all components on this the detailed modeling, as well as the virtual assembling of newly developed and existing digital models, which have been provided by different manufacturers, were possible without restrictions (**Figure 2**). Furthermore, in the first development phase, among others a collision analysis was conducted and the functionality of the different configurations of the prototype was tested. This allowed implementing optimi-

Fig. 1



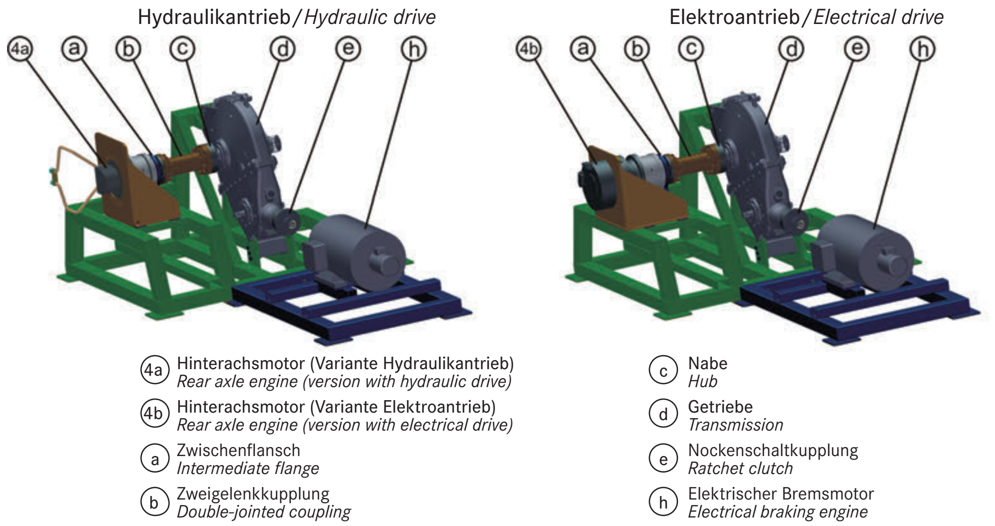
Schematic layout of the test bench to determine the efficiency of the rear axle traction drive components [6]

zations already at the digital prototype. In terms of the system robustness and the accuracy required for a smooth assembling of the components into the test bench, the analysis carried out on the digital prototype assured a minimisation of the design errors and significantly shortened the development time. Within the project, the cost and time savings achieved during the manufacturing of the physical prototype have been confirmed as some of the main benefits of digital prototyping (**Figure 3**).

Data acquisition and test bench control

The mechanical input power of the driveline can be measured at the input shaft of the hydraulic pump and the output torque

Fig. 2



Optional configurations of the digital prototype including test bench components

at the wheel hub flange. To calculate the output power the rotor position encoder of the braking machines are used in combination with the transmission ratio (**Figure 4**). Besides the mechanical parameters, also pressure and volume flow in the hydraulic system are logged to complete the data acquisition and to be able to calculate partial efficiency factors. The data logging rate is set to 100 Hz throughout the experiments.

Data logging and test bench control is done with a National Instruments CompactRIO-system in combination with Labview. Analog and digital inputs were used for logging the several transducer values, the CAN-interface enabled the control of the pump displacement via the BUS of the vehicle and the analog outputs set the values of the braking engines. The single operating points, which were computed on basis of field tests [8], are hold for a specific duration during the examinations, before the next torque-speed-pair is adjusted by the control hardware. Thereby is a stationary state combined with an automated test procedure. Due to the data export function in LabVIEW the logged data can be exported as text-files and can be imported into Matlab afterwards, which is the tool for further evaluation steps.

Results

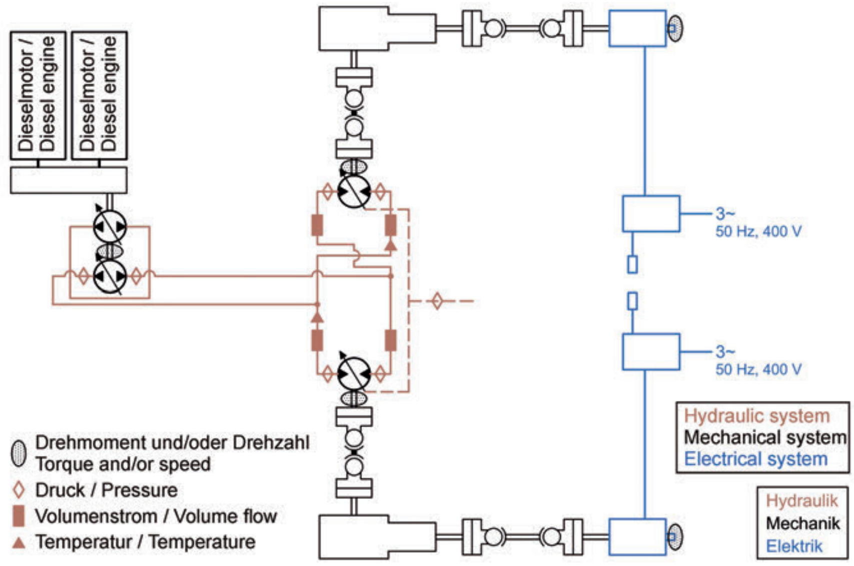
Figure 5 shows exemplarily the characteristics of the relevant parameters target wheel speed and target wheel torque during a test run. This represents solely the first drive quadrant with positive torque and speed and only includes torque-speed-pairs occurring in field tests with a relative frequency higher than 1 % [8]. For operating points with less frequency and for the three other drive quadrants, independent operation point files are generated. Every single working point file is approached on the test bench three times in succession with different constant combustion engine speeds, so that the input speed of the pump varies. So there is enough data logged to get secured results.

Fig. 3

Test object including test bench components during tests in the experimental hall (Photo: M. Heckmann, TU München)

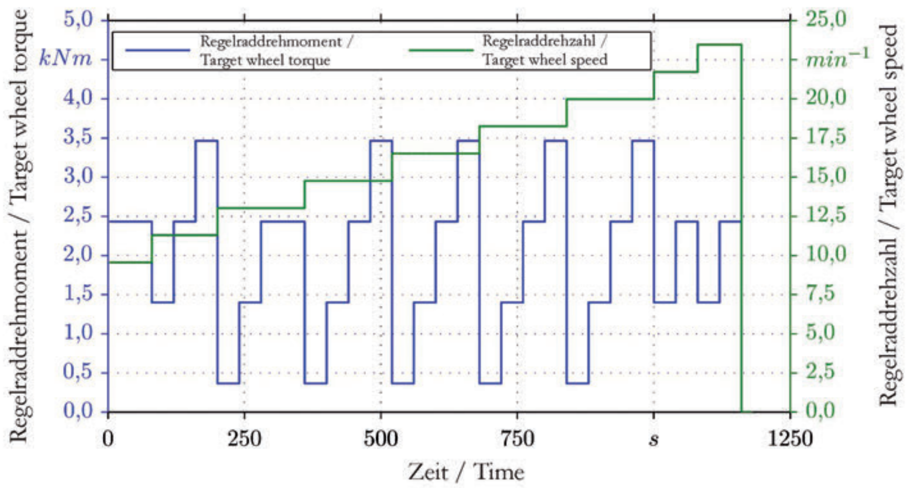
In order to evaluate the functionality of the test bench, the target values have to be compared to the actual values. Therefore the interaction between torque and speed, especially for the hydraulic drive, has to be considered. **Figure 6** shows the deviation between the target and actual values of wheel torque and speed depending on each other. In the third dimension the relative frequency of the measurement values are shown. It can be derived, if target deviations of torque and speed occurred frequently during the examinations. A value pair without any deviation in torque and speed represents the complete matching of actual and target value. So within the red spectra ($10^{-2,0}$) all measured points are included which had a relative frequency of occurrence during the test bench experiments of more than one percent. For each data pair the target value is subtracted from the actual value. So it becomes clear that 74 % of all logged data pairs during the test bench experiments are within the aspired controller range.

Fig. 4



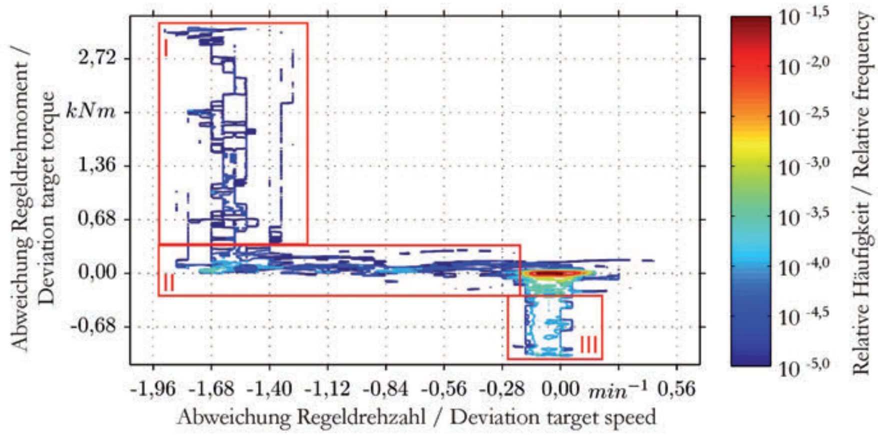
Measured values and transducer locations during test bench experiments ([7], modified)

Fig. 5



Example of a target test cycle for the load on the axle drive with variable values for torque and speed on both output sides

Fig. 6



Reproducibility of the targets of load and speed on the test bench in mutual dependence of target and actual deviation [7]

In **Figure 6** three different areas can be identified as a result of the test bench experiments: Sector I includes the reduction of the wheel torque occurring in combination with a rising volume flow. In this case the actual speed is clearly underneath the target speed. The constellation occurs at 1 000 s in the target value file, for instance shown in **Figure 5**. This represents the prior adjustment of the torque control. First torque is controlled without any adjustment of speed. The following wheel speed adjustment with very small deviations in torque leads to sector II. Within a speed class (n = constant), the stepwise rising of the torque leads to sector III.

Conclusions

The evaluation shows that the test bench fulfills the requirements, especially with regard to the feasibility of the test cycles and the reproducibility of load spectra based on in-field data. Due to the automated execution of the test cycles a very high repeatability of the important parameters is achieved as well. Thus meaningful results in terms of total and partial efficiencies of the tested drivelines can be determined.

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